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signal was 10:1 or more above background, on average. (FIG. 8 is an artist's rendition of a display produced by the GEOVIS program marketed by Geospace Corporation.) Vertical seismic profiles and previous seismic data were used to establish time-to-depth conversion.

A test well was drilled to a depth of 1,000 feet to check the seismic interpretations that can be made from FIG. 8 by anyone of ordinary experience in the seismic art. The well line is shown in FIG. 8 at 180. The well logs confirmed gas sands at four of the five locations 170. The one not confirmed is the one intermediate in depth, which is barely contacted by the well as can be seen in FIG. 8. The conventional seismic reflection surface 160 turned out to be a shale layer sealing the uppermost gas sand 170. (Shales can have much higher acoustic velocities than surrounding substances which makes them strong seismic reflectors.) Only the uppermost of the five gas sands predicted by the present invention is predictable from the conventional seismic results. Note that the present invention indicates in this example the hydrocarbon deposits themselves, not a structure that may or may not trap or include hydrocarbons.

The electroseismic source signal used at Friendswood was constructed from a 60 Hz sinusoid, using Golay complementary pair sequences of length 1664, producing a sweep of duration 27.73 seconds. This sweep was repeated approximately 500 times for each of the Golay pair of signals. This repetition tends to reduce ambient noise, relative to the seismic signal, because the ambient noise occurs at random phases relative to the signal.

The field layout for the Friendswood test was similar to that shown in FIG. 7. The length of the electrode wires was approximately 800 feet and the electrode spacing was approximately 650 feet. Geophones were placed at 180 surface locations on an 18x10 grid to the outside of one of the electrodes only, this being sufficient to test the method. Two sets of geophone strings were used at each surface location. The geophones on one string differed from those on the other only in the direction of the coil windings. The geophones used operate on the principle that slight tremors move a wire coil through a fixed magnetic field generating an electric signal. Reversing the coil windings reverses the polarity of the unwanted electromagnetic pickup without affecting the desired signal generated by the moving coil. Combining the outputs of the two oppositely wound geophone strings tends to produce a cancellation of unwanted pickup.

The signal generator, which may be called a power waveform synthesizer, used in the Friendswood test produced a power output of approximately 100 kw, delivered at 120 volts peak voltage. Because the impedance of the ground is low, the waveform synthesizer must be capable of high current levels. The primary challenge in designing or assembling such a power synthesizer is in meeting the high power (current) requirements. This can be done by persons skilled in hardware design using commercially available components.

Finally, the applied electrical signals were recorded in the field as they were transmitted into the ground at Friendswood. This record is then used as the correlation reference waveform in the data processing stage, thus providing the most accurate reference waveform possible, one that accounts for actual line voltage and similar fluctuations. The recorded signal may either be a voltage signal or a current signal. In the case of the test example represented by FIG. 8, a current signal was recorded.

The foregoing description is directed to particular embodiments of the present invention for the purpose of

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illustrating it. It will be apparent, however, to one skilled in the art that many modifications and variations to the embodiments described herein are possible. For example, other source waveform elements and binary sequences can be used as long as they satisfactorily meet the five requirements listed above. As noted previously, correlation side lobe amplitude varies inversely with the length of the extended waveform segment for any pseudo-random waveform. Thus, there are many possible choices of waveform element and binary sequencing that will give satisfactory results within the framework of the present invention as described above. Moreover, the present invention does not require that the source waveform be generated by binary sequencing of a single waveform element, or by binary sequencing in any manner. All such modifications and variations are intended to be within the scope of the present invention, as defined in the appended claims.

We claim:

1. A method for electroseismic prospecting of a subterranean formation, said method comprising the steps of:

selecting a source waveform and corresponding reference waveform, said two waveforms being selected to reduce amplitudes of side lobes produced by correlating said source waveform with said reference waveform;

generating said source waveform as an electrical signal and transmitting said electrical signal into said subterranean formation;

detecting and recording seismic signals resulting from conversion of said electrical signal to seismic energy in said subterranean formation; and

correlating said recorded seismic signals with said reference waveform.

2. The method of claim 1, wherein said source waveform is constructed from a single element, said element consisting of a single full cycle of a preselected periodic waveform, said elements being pieced together with polarities sequentially specified by a preselected binary code, said periodic waveform having a frequency predetermined to give desired depth penetration of said subterranean formation.

3. The method of claim 2, wherein said waveform element is a single cycle of a 60 Hz sinusoid.

4. The method of claim 2, wherein said waveform element is constructed from selected phases of a three-phase power supply to have a desired frequency less than 60 Hz.

5. The method of claim 2, wherein said binary code is pseudo-random, said source waveform has a predetermined length, said length being sufficient to further reduce said correlation side lobes to a predetermined level, said reference waveform is said source waveform, and said correlation is circular correlation.

6. The method of claim 5, wherein said binary code is a maximal length shift-register sequence.

7. The method of claim 2, wherein said binary code is a maximal length shift-register sequence with said resulting source waveform modified such that negative polarity elements in said source waveform are zeroed, said reference waveform is said source waveform before said negative polarity waveform elements are zeroed, and said correlation is circular correlation.

8. A method for electroseismic prospecting of a subterranean formation, said method comprising the steps of:

constructing a first source waveform and a second source waveform from a single element, said element consisting of a single full cycle of a preselected periodic waveform, said periodic waveform having a frequency

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predetermined to give desired depth penetration of said subterranean formation, said elements being pieced together with polarities specified sequentially by one member of a Golay complementary pair of binary sequences in the case of said first source waveform, and by the second member of said Golay complementary pair in the case of said second source waveform;

generating each of said two source waveforms as an electrical signal, and transmitting each said electrical signal, in turn, into said subterranean formation;

detecting and recording seismic signals resulting from conversion of said electrical signals to seismic energy in said subterranean formation;

correlating said recorded seismic signals from each of said source waveforms with said respective source waveform itself; and

summing said pair of correlations of said recorded seismic signals and their corresponding source waveform.

9. The method of claim 8, wherein said waveform element is a single cycle of a 60 Hz sinusoid.

10. The method of claim 8, wherein said Golay complementary pair of binary sequences are selected from other Golay pairs using the criteria of smallest autocorrelation side lobe amplitudes prior to summing.

11. An electrical signal for use in electroseismic prospecting of a subterranean formation, said signal having a waveform constructed from a single element, said element consisting of a single full cycle of a preselected periodic waveform, said elements being pieced together with polarities sequentially specified by a preselected binary code, said periodic waveform having a frequency predetermined to give desired depth penetration of said subterranean formation, said binary code being selected to generate side lobe amplitudes below a predetermined level when the signal waveform is correlated with itself.

12. The electrical signal of claim 11, wherein said waveform element is a single cycle of a 60 Hz sinusoid.

13. The electrical signal of claim 11, wherein said waveform element is constructed from selected phases of a three-phase power supply to have a desired frequency less than 60 Hz.

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14. The electrical signal of claim 11, wherein said binary code is pseudo-random and said correlation is circular correlation.

15. The electrical signal of claim 14, wherein said signal waveform has a predetermined length, said length being sufficient to further reduce said side lobe amplitudes to a predetermined level.

16. The electrical signal of claim 14, wherein said binary code is a maximal length shift-register sequence.

17. An electrical signal for use in electroseismic prospecting of a subterranean formation, said signal having a waveform constructed from a single element, said element consisting of a single full cycle of a preselected periodic waveform, said periodic waveform having a frequency predetermined to give desired depth penetration of said subterranean formation, said elements being pieced together with polarities sequentially specified by a maximal length shift-register sequence, said resulting signal waveform being modified such that resulting negative polarity elements are zeroed.

18. A pair of complementary electrical signals for use in conjunction with each other in electroseismic prospecting of a subterranean formation, said signals having waveforms constructed from a single element, said element consisting of a single full cycle of a preselected periodic waveform, said periodic waveform having a frequency predetermined to give desired depth penetration of said subterranean formation, said elements being pieced together with polarities sequentially specified by one member of a Golay complementary pair of binary sequences in the case of one of said two electrical signals, and by the second member of said Golay complementary pair in the case of the other electrical signal.

19. The electrical signals of claim 18, wherein said waveform element is a single cycle of a 60 Hz sinusoid.

20. The electrical signals of claim 18, wherein said waveform element is constructed from selected phases of a three-phase power supply to have a desired frequency less than 60 Hz.

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